CHAPTER 1

PRINCIPLES OF HELICOPTER FLIGHT

Basic flight theory and aerodynamics are considered in full detail when an aircraft is designed. The rotor repairer must understand these principles in order to maintain aircraft safely and to make repairs that are structurally sound and aerodynamically smooth.

AERODYNAMICS

Aerodynamics deals with the motion of air and with the forces acting on objects moving through air or remaining stationary in a current of air. The same principles of aerodynamics apply to both rotary-wing and fixed-wing aircraft. Four forces that affect an aircraft at all times are weight, lift, thrust, and drag:

- Weight is the force exerted on an aircraft by gravity. The pull of gravity acts through the aircraft's center of gravity, which is the point at which an aircraft would balance if suspended. The magnitude of this force changes only with a change in aircraft weight.
- Lift is produced by air passing over the wing of an airplane or over the rotor blades of a helicopter. Lift is the force that overcomes the weight of an aircraft so that it can rise in the air.
- Thrust is the force that moves an aircraft through the air. In a conventional fixed-wing aircraft, thrust provided by the propeller moves the plane forward while the wings supply the lift. In a helicopter both thrust and lift are supplied by the main rotor blades.
- Drag is the force of resistance by the air to the passage of an aircraft through it. Thrust force sets an aircraft in motion and keeps it in motion against drag force.

Any device designed to produce lift or thrust when passed through air is an airfoil. Airplane wings, propeller blades, and helicopter main and tail rotor blades are all airfoils (Figure 1-1).

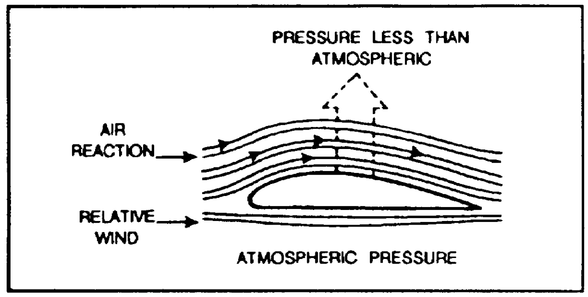

Figure 1-1. Example of an airfoil

Chord is the distance, or imaginary line, between the leading and the trailing edge of an airfoil. The amount of curve, or departure of the airfoil surface from the chord line, is known as the camber. Upper camber refers to the upper surface; lower camber refers to the lower surface. If the surface is flat, the camber is zero. The camber is positive if the surface is convex (curves outward from the chord line). The camber is negative if the surface is concave (curves inward toward the chord line). The upper surface of an airfoil always has positive camber, but the lower surface may have positive, negative, or zero camber (Figure 1-2).

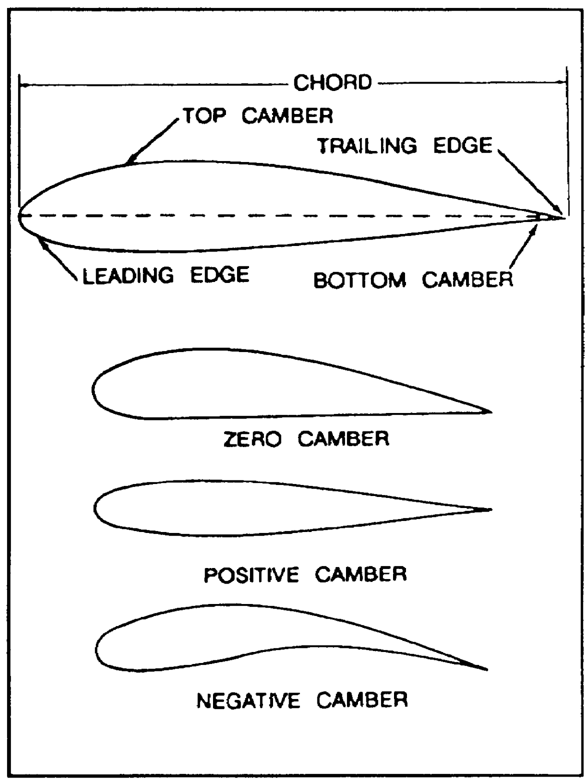

Figure 1-2. Airfoil features

BERNOULLI'S PRINCIPLE

Bernoulli, an eighteenth century physicist, discovered that air moving over a surface decreases air pressure on the surface (Figure 1-3). As air speed increases, surface air pressure decreases accordingly. This is directly related to the flight of an aircraft. As an airfoil starts moving through the air, it divides the mass of air molecules at its leading edge. The distance across the curved top surface is greater than that across the relatively flat bottom surface. Air molecules that pass over the top must therefore move faster than those passing under the bottom in order to meet at the same time along the trailing edge. The faster airflow across the top surface creates a low-pressure area above the airfoil. Air pressure below the airfoil is greater than the pressure above it and tends to push the airfoil up into the area of lower pressure. As long as air passes over the airfoil, this condition will exist. It is the difference in pressure that causes lift. When air movement is fast enough over a wing or rotor blade, the lift produced matches the weight of the airfoil and its attached parts. This lift is able to support the entire aircraft. As airspeed across the wing or rotor increases further, the lift exceeds the weight of the aircraft and the aircraft rises. Not all of the air met by an airfoil is used in lift. Some of it creates resistance, or drag, that hinders forward motion. Lift and drag increase and decrease together. They are therefore affected by the airfoil's angle of attack into the air, the speed of airflow, the air density, and the shape of the airfoil or wing.

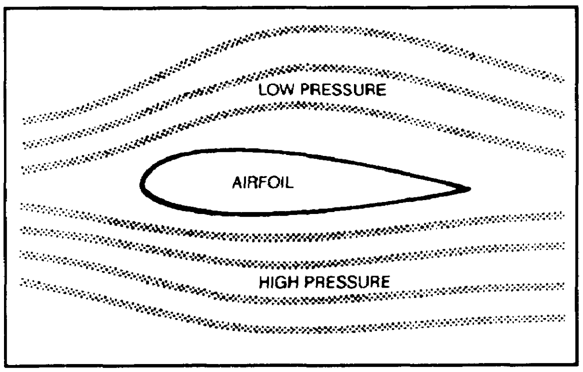

Figure 1-3. Bernoulli's principle

LIFT AND THRUST

The amount of lift that an airfoil can develop depends on five major factors:

- Area (size or surface area of the airfoil).
- Shape (shape or design of the airfoil sections).
- Speed (velocity of the air passing over the airfoil).
- Angle of attack (angle at which the air strikes the airfoil).
- Air density (amount of air in a given space).

Area and Shape

The specific shape and surface area of an airfoil are determined by the aircraft manufacturer. An airfoil may be symmetrical or unsymmetrical, depending on specific requirements. A symmetrical airfoil is designed with an equal amount of camber above and below the airfoil chord line. An unsymmetrical airfoil has a greater amount of camber above the chord line. An airfoil with a smooth surface produces more lift than one with a rough surface. A rough surface creates turbulence, which reduces lift and increases drag.

Speed

The speed of an airfoil can be changed by the speed of the engine or by the angle of the blade. The lift developed by an airfoil increases as speed increases. However, there is a limit to the amount of lift because the drag (resistance) of the airfoil also increases as speed increases.

Angle of Attack

The angle of attack is the angle between the airfoil chord and the direction of relative wind. Direction of airflow in relation to the airfoil is called <u>relative wind.</u> Lift increases as the angle of attack increases up to a certain point. If the angle of attack becomes too great, airflow over the top of the airfoil tends to lose its streamlined path and break away from the contoured surface to form eddies (burbles) near the trailing edge. When this happens, the airfoil loses its lift, and it stalls. The angle of attack at which burbling takes place is called the <u>critical angle of attack.</u>

Air Density

The density (thickness) of the air plays an important part in the amount of lift an airfoil is able to make. The air nearest the earth's surface is much denser than air at higher altitudes. Therefore, an aircraft or helicopter can achieve more lift near the ground than at a high altitude. While keeping at the same speed and angle of attack, an airfoil will slowly make less lift as it climbs higher and higher.

AIRFOIL STABILITY

Center of Pressure

The resultant lift produced by an airfoil is the difference between the drag and lift pressures of its upper and lower surfaces. The point on the airfoil chord line where the resultant lift is effectively concentrated is called the center of pressure. The center of pressure of a symmetrical airfoil remains in one position at all angles of attack. When the angle of attack of an unsymmetrical airfoil changes, the center of pressure changes accordingly: the center of pressure moves forward with an increase in angle of attack, and the center of pressure moves backward with a decrease in angle of attack.

Airfoil Aerodynamic Center

The aerodynamic center of an airfoil is the point along the chord line about which the airfoil tends to rotate when the center of pressure moves forward or backward between the leading and trailing edges.

Torque

According to Newton's third law of motion, for every action there is an equal and opposite reaction. As a helicopter main rotor or an airplane propeller turns in one direction, the aircraft fuselage tends to rotate in the opposite direction. This effect is called torque. Solutions must be found to counteract and control torque during flight. In helicopters torque is applied in a horizontal rather than a vertical plane. The reaction is therefore greater because the rotor is long and heavy relative to the fuselage, and forward speed is not always present to correct the twisting effect.

Gyroscopic Precession

If a force is applied against a rotating body, the reaction will be about 90° from the point of application, in the direction of rotation. This unusual fact is known as gyroscopic precession. It pertains to all rotating bodies. For example, if you push the 3-o'clock point on a clockwise rotating wheel, the wheel would move as if it had been pushed at the 6-o'clock point. The rotors on helicopters act as gyroscopes and are therefore subject to the action of gyroscopic precession.

STRESS

Stress is a force placed on a body measured in terms of force (pounds) per unit area (square inches). Aircraft design engineers design aircraft to meet – even to exceed – strength requirements of military service. Since Army aircraft are operated under combat conditions, they might exceed these design limits. Therefore, maintenance personnel must check constantly for failures and for signs of approaching failure in aircraft structural units. Stress may take the form of compression, torsion, tension, bending, or shear or may be a combination of two or more of these forces (Figure 1-4):

- Compression is resistance to being pushed together or crushed. Compression is produced by two forces pushing toward each other in the same straight line. The landing struts of an aircraft are under compression after landing.
- Torsion is resistance to twisting. A torsional force is produced when an engine turns a crankshaft. Torque is the force that produces torsion.
- Tension is resistance to being pulled apart or stretched. Tension is produced by two forces pulling in opposite directions along the same straight line. Pilots put the cables of a control system under tension when they operate the controls.
- Bending is a combination of tension and compression. The inside curve of the bend is under compression, and the outside curve is under tension. Helicopter main rotor blades are subjected to bending.
- Shear is the stress exerted when two pieces of metal fastened together are separated by sliding one over the other in opposite directions. When force is applied to two pieces of metal fastened together by rivets or bolts, sliding them across each other, the rivets or bolts are subjected to shear. Stress will cut off the bolt or rivet like a pair of shears. Generally, rivets are subjected to shear only, but bolts may be stressed by shear and tension. There is internal shear in all parts being bent such as the skin of sheet metal structures.

LEVERS AND MOMENT OF FORCE

A lever is a useful device found in tools such as jacks, shears, wrenches, and pliers. To use tools and balancing procedures correctly, the repairer needs to understand moment of force (amount of leverage).

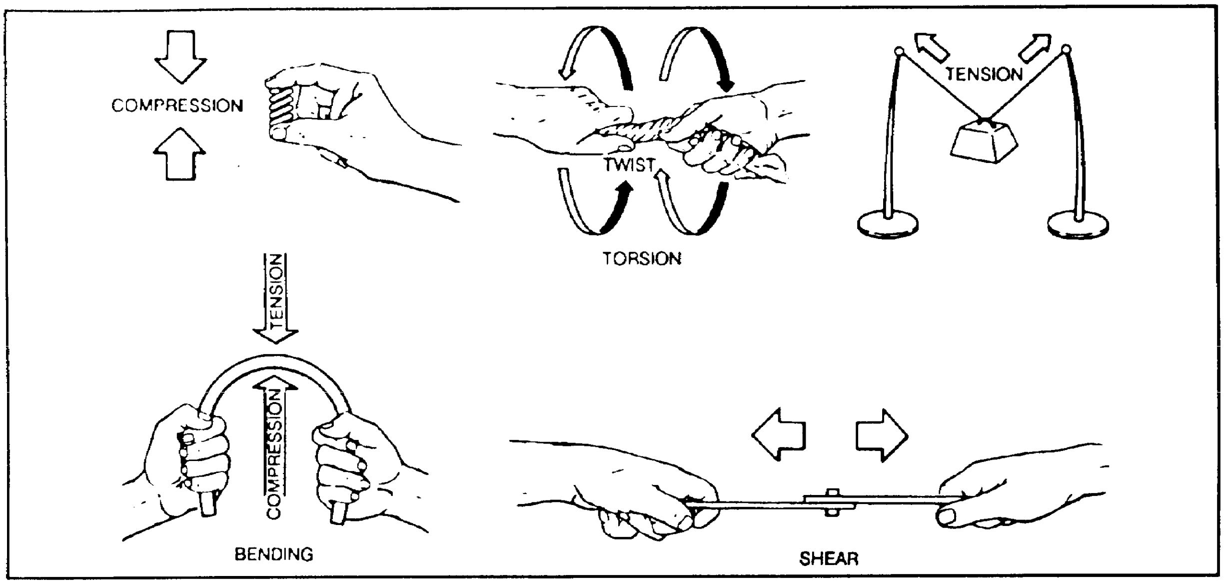

Figure 1-4. Types of stresses

Levers

Levers are classified as three types according to the position of the applied force (effort), the resistance, and the fulcrum (the pivot point) (Figure 1-5). In Type 1 the fulcrum is located between the applied effort and the resistance. In Type 2 the resistance is located between the fulcrum and the applied effort. In Type 3 the applied effort is located between the resistance and the fulcrum.

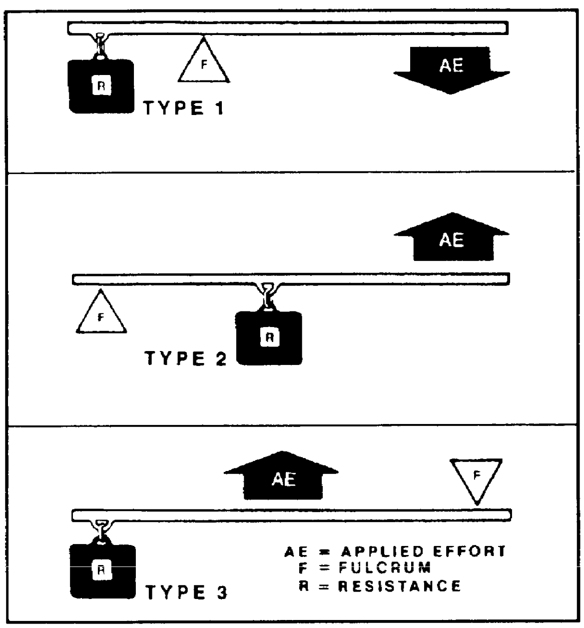

Figure 1-5. Types of levers

Mechanical advantage is the ratio between the resistance and the effort applied to a lever. This is expressed in the following formula:

$$MA = \frac{R}{E}$$

MA = mechanical advantage

R = resisting force (weight moved)

E = effort (applied force)

Proper use of mechanical advantage enables a relatively small force to overcome a larger resisting force by applying the effort through a longer distance than the resistance is moved. For example, to lift a 4-pound weight (R) which is 2 inches from the fulcrum of a Type 1 lever requires 1 pound of effort (E) applied 8 inches from the fulcrum. The mechanical advantage of this lever would be as follows:

$$MA = \frac{R}{E} = \frac{4}{1} = 4$$

Thus, the applied effort in the example would move through a distance that is four times greater than the distance the resistance would move.

Moment of Force

A moment of force is the product of a force or weight and a distance. To find a lever's moment of force, multiply the applied effort by the distance between the point of effort application and the pivot point (fulcrum). If the moment of force of the applied effort equals the moment of force of the resistance, the lever will balance. If an object to be balanced on a Type 1 lever weighs 4 pounds and is located 2 inches from the fulcrum, it could be balanced by a 2-pound effort applied 4 inches from the fulcrum on the opposite side or by a l-pound effort applied 8 inches from the fulcrum.

VIBRATION

Any type of machine vibrates. However, greater than normal vibration usually means that there is a malfunction. Malfunctions can be caused by worn bearings, out-of-balance conditions, or loose hardware. If allowed to continue unchecked, vibrations can cause material failure or machine destruction. Aircraft – particularly helicopters – have a high vibration level due to their many moving parts. Designers have been forced to use many different dampening and counteracting methods to keep vibrations at acceptable levels. Some examples are —

- Driving secondary parts at different speeds to reduce harmonic vibrations; this method removes much of the vibration buildup.
- Mounting high-level vibration parts such as drive shafting on shock-absorbent mounts.
- Installing vibration absorbers in high-level vibration areas of the airframe.

Lateral

Lateral vibrations are evident in side-to-side swinging rhythms. An out-of-balance rotor blade causes this type of vibration. Lateral vibrations in helicopter rotor systems are quite common.

Vertical

Vertical vibrations are evident in up-and-down movement that produces a thumping effect. An out-of-track rotor blade causes this type vibration.

High-Frequency

High-frequency vibrations are evident in buzzing and a numbing effect on the feet and fingers of crew members. High-frequency vibrations are caused by an out-of-balance condition or a high-speed, moving part that has been torqued incorrectly. The balancing of high-speed parts is very important. Any buildup of dirt, grease, or fluid on or inside such a part (drive shafting for example) causes a high-frequency vibration. This type vibration is more dangerous than a lateral or vertical one because it causes crystallization of metal, which weakens it. This vibration must be corrected before the equipment can be operated.

Ground Resonance

Ground resonance is the most dangerous and destructive of the vibrations discussed here. Ground resonance can destroy a helicopter in a matter of seconds. It is present in helicopters with articulated rotor heads. Ground resonance occurs while the helicopter is on the ground with rotors turning it will not happen in flight. Ground resonance results when unbalanced forces in the rotor system cause the helicopter to rock on the landing gear at or near its natural frequency. Correcting this problem is difficult because the natural frequency of the helicopter changes as lift is applied to the rotors. With all parts working properly, the design of the helicopter landing gear, shock struts, and rotor blade lag dampeners will prevent the resonance building up to dangerous levels. Improper adjustment of the landing gear shock struts, incorrect tire pressure, and defective rotor blade lag dampeners may cause ground resonance. The quickest way to remove ground resonance is to hover the helicopter clear of the ground.

NONDESTRUCTIVE INSPECTION

Nondestructive inspection (NDI) methods determine integrity, composition, physical/electrical/thermal properties, and dimensions without causing a change in any of these characteristics in the item being inspected. NDI includes —

- Liquid penetrant methods.
- Magnetic particle methods.
- Electromagnetic methods.
- Ultrasonic methods.
- Penetrating radiation.
- Harmonic bond testing.

NDI in the hands of a trained and experienced technician is capable of detecting flaws or defects with a high degree of accuracy and reliability. Maintenance engineering personnel should know the capabilities of each method. Equally important, they should recognize the limitations of each method. NDI is not a panacea for inspection ills – it is merely a means of extending the human senses. No NDI method should ever be considered conclusive. A defect indicated by one method must be confirmed by some other method to be reliable. Further, NDI equipment is highly sensitive and capable of detecting discontinuities and anomalies which may be of no consequence to the particular service a component is used for. Limits for acceptance and rejection are thus as much apart of an inspection as the method itself. For example, ultrasonic inspection equipment is fully capable of detecting normal grain boundaries in some cast alloys. Inspection criteria must be designed to overlook these “normal” returns and to discriminate in favor of those discontinuities that will affect the component in service.